Challenges and prospects for dynamical cores of oceanic models across all scales

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1 - Major differences compared to atmospheric modeling

- Density variations are quite small compared to the mean density

- Validity of hydrostatic balance \((\rho g \approx \text{const})\): in the ocean the hydrostatic balance is violated approximately for \(L < 1 \text{ km}\) and weak stratification

- Ocean non-hydrostatic models are at early development stage

- Stiffness \((c_0 \gg u)\): fast surface gravity waves

- Forced explicit treatment of 2D barotropic mode (+ consistency enforcement)

- Away from boundary layers, tracers are stirred and mixed preferentially along isopycnal surfaces \(\nabla \rho \approx 10^{-3} \text{ m}^{-1} \text{ molecule}^{-1}\) (e.g. Ledwell et al., 1993; \(N_{b} \approx 10^3 \text{ molecule}^{-1}\) for \(L_0 \approx 100 \text{ km}\)

- Complex geometry (but no “Pole problem”)

- Computational domain is bounded with irregular boundaries

- Vacuum states (wetting and drying)

- Volume-conserving treatment of dry states and non-negativity of water heights

2 - Overview of equations and associated modeling assumptions

- Geometric assumptions
  - spherical geoid, traditional shallow-fluid
  - fixed bathymetry \(\approx \frac{1}{2}N_{b} L_{0} \times L_{0} \times L_{0} \approx \text{a few } 10^3 \text{ m}^3\)

- Boussinesq
  - \(\approx \text{in-situ density}\) \(\rho \approx \rho_0\) except when associated with the gravitational term

- Hydrostatic

- Thermodynamically consistent description of seawater (Gibbs function)

- Potential temperature \(\Theta\) is replaced by the conservative temperature \(\Theta = \Theta_{0} - (\frac{1}{ho_0} \frac{d}{dt} \log \rho)\)

- Mode splitting: fast surface gravity waves are integrated separately (depth independent barotropic mode approximation)

- Barotropic (internal) mode

- Baroclinic (external) mode

3 - Brief overview of some existing dynamical cores

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<th>vertical grid</th>
<th>Model option</th>
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4 - Some prospects for ocean dynamical cores

- Control of spurious modes 
- Spectral gap with FE discretization
- Control of spurious modes for nonlinear scalar conservation laws

5 - Challenges

- Challenges for unstructured meshes: High-order methods and Local time-stepping
- Energy consistency and resolved/ unresolved scales coupling
- Discrete closing of the energy budget
- Design of energy-conserving space and time discretizations
- Control of energy, non-negativity and dry states for nonlinear scalar conservation laws

- Stable and consistent coupling with other Earth-system components

- Multi-resolution strategies with local adaptation of model equations

6 - Toward a “DCMIP-like” test-case suite

- Any suggestion for semi-idealized testcases are welcome

References


Context: the ocean model developers community has had the tendency to be split depending on target applications (global vs coastal) and on the type of horizontal grids (structured vs unstructured).